APPENDIX A

PREDICTING EVAPOTRANSPIRATION DEMANDS FOR WETLANDS

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PREDICTING EVAPOTRANSPIRATION DEMANDS FOR WETLANDS

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Abstract. Wetlands, by their nature, have free access to water for fulfilling evaporation and transpiration demands. However, because wetlands are often surrounded by vegetation that has less access to water, evapotranspiration demands on wetlands can be greater than a simple weather data analysis might indicate, due to advective transfer of energy into the wetland. This is especially true in arid regions and where tall wetland vegetation having limited areal expanse can be subjected to increased evapotranspiration through oasis and clothesline effects. Because artificially created wetlands may require artificially sustained water supplies, it is important to quantify the consumptive water requirements. General procedures are presented for estimating evapotranspiration from wetlands as a function of the size, height, density, and ardity of the surrounding area. Evapotranspiration coefficients (K_c) are summarized from studies of cattail and bulrush wetlands in Utah and Florida. The Utah data include measurements of evapotranspiration from large wetlands and from small, narrow wetlands. Values for K_c range from 1.1 for large wetlands in Florida to 1.3 for large wetlands in Utah to 1.8 for narrow, isolated wetlands in Utah that are surrounded by poorly irrigated pasture.

In addition to the coefficients presented, surface and aerodynamic characteristics of cattail wetlands are presented that allow for the direct application of a Penman-Monteith evapotranspiration equation. Direct application of a resistance-based equation is challenging due to the complexity of wetland canopies, and especially for small wetlands, where assumptions in the Penman equation of large expanses of uniform vegetation are violated.

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INTRODUCTION

The ability to estimate water use by phreatophytes and hydrophytes is useful in water balance studies of river basins, and in estimation of ground water recharge, stream flow depletion, and water requirements of wetlands. Hydrophytes are defined as vascular plants growing wholly or partly in water, especially those perennial aquatic plants having overwintering buds under water (Merriam, 1971). Two common types of hydrophytes in North American wetlands are the cattail (*Typha Latifolia*) and bulrush (*Scirpus lacustris*). Both of these hydrophytes are commonly observed along edges of marshes, ditches, lakes and ponds.

Many wetlands in the western United States are found along stream systems or along irrigation canals, return flow channels or seeps. Consequently, many wetlands are long and narrow. This makes it difficult to apply the traditional energy balance approach, where the Penman or Penman-Monteith equation assumes that the expanse of the vegetation being predicted is nearly infinite. The result of small stands of wetland vegetation are larger than normal cover coefficients[2] (K_c) due to the so-called "clothesline" effects.

Description of Vegetation

Cattails are characterized by a mass of generally 10 or more leaf blades that are about 1 to 3 m long and 3 cm wide. The leaf blades protrude diagonally and vertically from an oval stalk. The plant produces a large seed head (15 cm long by 4 cm diameter) at the top of the stalk at about a 1.5 m height. The root stalk of the cattail is perennial and is often found in saturated soils. All vegetative growth occurs annually and is damaged by frost, to which it is sensitive.

Bulrushes are characterized by long, narrow, round leaf swords which grow vertically and diagonally from a central stalk and grow to a 1 to 2 m height. The round leaf swords average about 1 cm in diameter. The bulrush plant produces several small seed heads near the top of the stalk. As with cattails, the root stalk of the bulrush is perennial and often occurs in saturated soils. All vegetative growth occurs annually.

Hydrophytes often grow in patchy, long, narrow stands in wetlands along streams and canals, where the average width of the stand is only 1 to 10 m. Therefore, the heat, air movement and vapor exchange between these stands and the atmospheric boundary layer have two or three dimensions and do not conform to the relationships that characterize large fields. In large fields, evapotranspiration (ET) and heat exchange can be modelled as one-dimensional and as occurring

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[2]The "cover coefficient" is defined as the ratio of ET from the vegetation (or cover) to the reference ET (ET_r). The cover coefficient is synonymous with the "crop coefficient" used with agricultural crops.

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from a uniform exchange surface having an equilibrium boundary layer over the surface (Brutsaert 1982). The complex exchanges over narrow strips of vegetation are affected by height, density, shape and extent of the vegetative canopy, and violate the assumptions implicit in the Penman and Penman-Monteith equations. A large amount of data is required to completely model such exchanges. Therefore, in practice, ET from small stands of vegetation is generally estimated by employing empirical modifications to Penman equations (even though these equations are violated) or by deriving empirical evapotranspiration cover coefficients (K_c).

PAST STUDIES

Studies of water use by aquatic plants and hydrophytes began more than 70 years ago with Otis (1914) reporting water use by cattails which was 3 times that of evaporation from open water (E_0). Much of the extra water use was due to the experimental design of Otis, where 0.8 m diameter cattail stands were exposed on all sides to advective energy (Anderson and Idso, 1987), and were therefore unrepresentative of all but the most extreme cases of isolated, small stands of hydrophyte vegetation.

Young and Blaney (1942) conducted studies on native vegetation and reported water use by hydrophyte stands which was 40% greater than E_0. The Young-Blaney lysimeters were surrounded by stands of similar vegetation which served to reduce the area of lysimeter vegetation intercepting net radiation, helped contain lysimeter vegetation within the lysimeters, and reduced advective flow of air into lysimeter vegetation.

Anderson and Idso (1987) presented general relationships between ET/E_0 and the ratio of total exposed area of vegetative outline to horizontal surface area. ET from cattails in exposed 2.3 m diameter lysimeters surrounded by dry fetch ranged from 2 to 5 times E_0, which envelopes the ratio reported by Otis (1914). The Anderson-Idso cattail study was conducted in a research facility surrounded by fallow fields and residential development and with direct exposure of the lysimeter vegetation, which is uncharacteristic of most native conditions. The studies by Otis, Young and Blaney, and Anderson and Idso reflect the variation in reported ratios of ET to E_0 as exposure and relative stand size change.

Prueger (1991) measured ET from cattail and bulrush vegetation using 1 m^2 constant water table lysimeters centered within 36 m^2 stands of vegetation. The vegetation stands were bordered by irrigated pasture. Allen et al. (1992) fit aerodynamic roughness and bulk stomatal resistance parameters and evapotranspiration coefficients to these ET measurements, which represented narrow, isolated stands of cattail and bulrush vegetation. Peak ratios of ET from the centers of the 6 m wide stands to alfalfa reference ET (ET_r) averaged 1.6 for cattails and 1.8 for bulrushes. A ratio of momentum roughness height (z_{om}) to vegetation height (h) of 0.3 and single leaf resistance (r_l) equal to 200 s m^{-1} for cattails and 150 s m^{-1} for bulrushes best fit the experimental data using the Penman-Monteith equation .

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Errors between prediction equations and lysimeter measurements were minimized by Allen et al. (1992) using linear, segmented FAO type evapotranspiration coefficient curves. The large K_c's for the narrow stands were caused by the clothesline effect of the tall vegetation surrounded by short grass pasture.

Allen et al. (1994) reported aerodynamic and surface resistance parameters for a large, dense stand of cattails in northern Utah using Bowen ratio ET measuring systems placed on the edge of a 9 ha area. They found the ratio of ET to ET_r to average about 1.15 during the peak period. The 1.15 K_c represents the cover coefficient for a large expanse of cattail vegetation, as compared to the $K_c = 1.6$ reported by Allen et al. (1992) which represents small stands and wetlands within the same climatic region. In applying the Penman-Monteith equation to the large cattail wetland, Allen et al. (1994) used a bulk surface resistance $r_s = 45$ s m^{-1} and z_{om} / H ratio $= 0.12$ for the midseason period, which are similar to values used for alfalfa; the only difference being the 2 to 3 m height of the cattail vegetation as compared to the 0.5 m average height for alfalfa. Allen et al. (1994) found measured net radiation, R_n, for the dense cattails to be very close to that for alfalfa, indicating a similar albedo (about 0.23).

Abtew and Obeysekera (1995) measured ET from a large cattail wetland in southern Florida using a 10 m^2 constant water table lysimeter. Their reported measurements indicate a midseason $K_c = 1.00$, based on an alfalfa reference (ASCE Penman-Monteith with 0.5 m alfalfa). Abtew and Obeysekera (1995) found $r_s = 100$ s m^{-1} for $z_{om} / H = 0.12$ for the entire season. Because their K_c's were 40% lower during the October - April period, their r_s would have been lower, perhaps 50 to 60 s m^{-1}, during the midseason period (May - August).

It is clear, based on the range of K_c's reported from various studies, that the local climate and surroundings play a substantial role in the peak or midseason K_c for a wetland. Allen et al. (1994) suggested using an approach similar to that presented in Fig. 1 to estimate the midseason K_c for tall wetland vegetation, where the K_c is varied according to the size of the stand (minimum dimension) and the relative ET of the surroundings. This figure needs to be modified (filled in) by future research and measurements and by summary and characterization of previous studies.

THE COVER COEFFICIENT APPROACH

Currently, the most common practice for estimating evapotranspiration requirements for agricultural and horticultural crops is to use a "crop" or "cover" coefficient (K_c) multiplied by an estimate of reference evapotranspiration (ET_r). This is a simple, yet robust, approach which has received repeated testing and use and is widely accepted by the agricultural and engineering communities (Smith et al., 1991). The cover coefficient is varied with time to reflect changes in ET_c relative to ET_r. The cover coefficient is a lumped parameter which considers all characteristics of the crop which are different from those of the ET reference crop. The ET_r

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estimate is calculated using available climatic data and usually represents an alfalfa reference or a clipped, cool season grass (Jensen et al., 1990). ET_c is computed as:

$$ET_c = K_c \, ET_r \qquad\qquad 1$$

The Penman-Monteith (P-M) form can be used to calculate ET_r (Allen et al., 1989; Jensen et al, 1990) or the 1982 Kimberly-Penman (Wright, 1982) or other calibrated equation can be used.

The advantages of the cover coefficient are that it encompasses all differences between the vegetative cover and the reference surface. The disadvantage is that it is difficult to estimate the change in K_c given a change in the height, LAI, or stomatal resistance of a stand.

Summary Table of Cover Coefficients

Table 1 includes a summary of K_c data and growth dates for the data summarized in the previous section. This information is also presented in Fig. 2 and 3. The simple FAO style of K_c curve was utilized due to its simplicity and due to the range in uncertainty and variation in the measured data. The FAO K_c curve is comprised of five straight line segments that represent the 1) "initial period", $K_{c\,ini}$; 2) the "development period"; 3) the "midseason period", $K_{c\,mid}$, 4) the "late season period", and 5) the "post death period" (or post dormancy period), $K_{c\,end}$. The initial, midseason, and post death periods are comprised of horizontal K_c line segments.

Table 1. Values of initial, midseason, and ending cover coefficients (K_c) and growth stage dates for cattail and bulrush wetlands.

Location	$K_{c\,ini}$	$K_{c\,mid}$	K_c end	Beg. Growth	Beg. Mid Seas.	End Mid Seas.	Death or Dorm.
Logan, Utah Small Stand - Cattails	0.3	1.6	0.3	5/1	6/15	9/15	10/1
Logan, Utah Small Stand - Bulrush	0.3	1.8	0.3	5/1	7/8	8/7	10/1
Logan, Utah Large Stand - Cattails	0.3	1.15	0.3	5/1	6/15	9/15	10/1
Southern Florida Large Stand - Cattails	0.6	1.0	0.6	3/15	5/1	9/15	10/15

Vegetation in all Utah locations was killed by the first occurrence of freezing (0 °C). Vegetation in southern Florida was somewhat dormant during the winter season (Abtew and Obeysekera (1995).

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When using the FAO style curve, where the midseason K_c (period of maximum growth and health) is represented by a horizontal line, the value for $K_{c\ mid}$ is not necessarily the peak K_c for the crop. The K_c for some individual days or for a short period can be greater than $K_{c\ mid}$. However, the difference is generally small. The growing season for cattail and bulrush vegetation ends with frost in northern latitudes. The K_c before growth initiation ($K_{c\ ini}$) and after death ($K_{c\ end}$) is a function of the health of the vegetation and the amount and frequency of wetting by precipitation. In northern Utah, $K_{c\ ini}$ averages about 0.3 due to relatively infrequent wetting during the nongrowing season. In Florida, where plants stay green, but somewhat dormant during the winter, and where precipitation is greater, $K_{c\ ini}$ averages about 0.6. Monthly K_c's determined from data reported by Abtew and Obeysekera (1995) are shown in Fig. 4. The length of the midseason portion of the curve drawn in Fig. 4 (and in Fig. 2) was based on the description of the period of maximum vegetation growth given in the Abtew paper. It appears that the ET from the cattail wetland decreased prior to September.

Measurements of ET during the initial period, as determined using a Bowen ratio ET measuring system are shown for dormant (dead) cattail vegetation in northern Utah in Fig. 5. In this figure, the 20-minute values are split into two general groups. These are measurements during and following precipitation (high values of LE from the wetland) and measurements where the dead vegetation was dry. The latter measurements averaged nearly zero. As indicated in Fig. 5, the wet vegetation surface, even though the vegetation was dead, caused evaporation rates from the wetland to exceed computed alfalfa reference ET by 2.2 times. This was due to the large roughness of the dead vegetation (average height of the dead vegetation was about 1 m) and zero surface resistance ($r_s = 0$) when the surface was wetted by rain. The values for $K_{c\ ini}$ and $K_{c\ end}$ are also influenced by the amount of open water within the wetland. These two values will increase as the fraction of open water increases.

OPEN WATER EVAPORATION

Evaporation from open water must be divided into two categories: evaporation from deep water bodies and evaporation from shallow water bodies. In the context of evaporation, deep water bodies are categorized as those water bodies where the mean water depth averages 1 m or more. Shallow water bodies are those where the mean water depth averages less than 1 m. The distinction between shallow and deep water bodies stems from the timing of transfer of net radiation (R_n) from the water body to the water surface for evaporation.

Water differs from vegetation in that the point of R_n adsorption is different from the point of evaporation. In vegetation, leaves absorb R_n and almost immediately convert the energy into either sensible energy to the air (H) or into evaporation (ET). Water, on the other hand, absorbs R_n beneath the water surface. The depth of the water layer absorbing the R_n depends on the turbidity of the water.

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The consequence of adsorption of R_n beneath the water surface is that the energy is not immediately available for evaporation, but is converted into heat within the upper water layer. The adsorbed energy, in the form of heat, must be transferred to the surface through conduction or convection. These processes may be slow, so that evaporation from the surface lags R_n. In deep, clear water bodies, the transfer of heat energy back to the surface is so dampened that it is essentially constant throughout a 24-hour period so that evaporation is almost constant day and night with no correlation with R_n rates (Amayreh, 1995).

Shallow water differs from deep water in the time delay between R_n absorption and transfer of H to the surface. In shallow water systems where all R_n is adsorbed in the upper 1 m of water, the transfer of energy back to the surface for evaporation is on the order of a week or less, so that when computed on a monthly time step, evaporation is strongly correlated with net radiation. In deep water systems, the absorption of R_n can be transferred into deep layers of the body so that the transfer of energy back to the surface can be delayed on the order of months. The effect of this is that evaporation from deep water bodies may not be closely related to R_n, even on monthly time steps. The result is a reduction in K_c's for deep open water evaporation in the spring and summer months when the water body is absorbing more radiation energy than is transferred to the water surface, and an increase in K_c's in the fall and winter months when transfer of heat to the surface exceeds incoming R_n and the water body cools. ·

An example of K_c's for a deep water body, relative to alfalfa and grass reference ET is given in Table 2 and in Fig. 6, where monthly K_c's during the March - November period are graphed for the Bear Lake system in Utah-Idaho. The Bear Lake averages more than 15 m depth and has a surface area of more than 200 km². The evaporation measurements were made using a Bowen ratio measuring system. Measurements were independently validated using measurements taken with an eddy correlation system (Amayreh, 1995).

Table 2. Evaporation measurements from Bear Lake, Utah-Idaho during 1994 based on Bowen Ratio and Eddy Correlation Measuring Systems (from Amayreh, 1995).

Month	Lake Evaporation (mm/day)	Grass Ref.ET$_o$ (mm/day)	K_c	Alfalfa Ref.ET$_r$ (mm/day)	K_c
March	1.3	1.8	0.75	2.3	0.60
April	1.6	2.7	0.61	3.4	0.49
May	2.0	4.0	0.49	5.0	0.39
June	2.2	5.1	0.45	6.4	0.36
July	2.6	5.3	0.45	6.6	0.36
August	2.4	4.9	0.48	6.1	0.38
September	2.2	3.5	0.60	4.4	0.48
October	1.6	1.7	0.95	2.1	0.76

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Evaporation from deep water bodies will definitely lag pan evaporation measurements due to the potentially very large heat storage term for the water body. The length of time lag depends on the depth of the water body and the range in mean air temperature between winter and summer (tropical water bodies would have a lower lag, since the water temperature would be in near equilibrium with mean annual air temperature).

Evaporation from shallow water bodies will follow pan evaporation measurements more closely, since the heat in the water is transferred to the surface more readily and because the water temperature comes into equilibrium with the air temperature more quickly. In general, evaporation from open water will be less than that from a NWS Class A evaporation pan since the relatively smooth water body creates less turbulence and consequently less vapor transfer than the evaporation pan, which is surrounded by relatively rough grass and other vegetation. In addition, the sides of the pan can collect additional radiation and heat as compared to open water. Many users estimate evaporation from shallow water bodies as $0.7 E_{pan}$.

RESISTANCE-BASED EQUATIONS FOR WETLAND EVAPOTRANSPIRATION

Background Equations

The Penman-Monteith equation can be calibrated to estimate ET from a wetland directly by determining parameters for the aerodynamic resistance and surface resistance terms and for albedo (reflectance) of solar radiation. As with all Penman combination equations, the Penman-Monteith method was developed to estimate ET from a large expanse of the same type of cover so that the assumptions within the equation are valid. The Penman-Monteith equation can be expressed as (Allen et al., 1989):

$$ET = \frac{\Delta (R_n - G) + \rho\, c_p\, \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)} \qquad (2)$$

where ET is evapotranspiration, R_n is net radiation, and G is soil heat flux, all having units of W m^{-2}; ρ is air density, kg m^{-3}; c_p is specific heat of dry air, J kg^{-1} $°C^{-1}$, and e_s and e_a are saturation vapor pressures of air at air temperature and dewpoint, respectively, kPa. Δ is the slope of the saturation vapor pressure curve and γ is the pyschrometric constant, kPa $°C^{-1}$, which can be computed according to Jensen et al. (1990). r_a is aerodynamic resistance to turbulent transfer of sensible heat and vapor from the plant surface into the atmosphere at the wind measurement height, s m^{-1}, and r_s is bulk canopy resistance, s m^{-1}. The strength of the Penman-Monteith

equation relative to more empirical forms of the Penman equation is that it directly accounts for aerodynamic resistance to turbulent diffusion and stomatal resistance to vapor transport.

Allen et al. (1989) presented relationships for estimating the values of r_a and r_s for dense vegetation under well-watered conditions where aerodynamic instability could be ignored:

$$r_a = \frac{\ln\left(\dfrac{z_a - d}{z_{om}}\right) \ln\left(\dfrac{z_t - d}{0.1\ z_{om}}\right)}{k^2\ u_a} \tag{3}$$

and z_a is the height of the anemometer (wind) measurement above the ground, m; and z_t is the height of temperature and relative humidity (or vapor pressure) measurements above the ground, m. Variable d is the zero plane displacement height of the vegetation, m; z_{om} is the momentum roughness height of vegetation, m; k is von Karman's constant for turbulent diffusion, equal to 0.41; and u_a is wind speed at the anemometer height, m s^{-1}. Allen et al. (1989) and Jensen et al. (1990) suggested using ratios of d/h and z_{om}/h of 0.67 and 0.123 for both alfalfa and grass, where h is the mean height of vegetation, m.

Canopy resistance for a uniform, dense canopy can be calculated as the quotient of individual leaf stomatal resistance (per area of leaf) and the total projected leaf area of the plant (Allen et al., 1989):

$$r_s = \frac{r_l}{LAI_{eff}} \tag{3}$$

where r_l is stomatal resistance of a single leaf per unit projected LAI, taken as 100 sm^{-1} for reference crops of alfalfa and grass. LAI is the projected leaf area index (defined as the total area of one side of flat leaves (m^2) per m^2 of ground surface), and LAI_{eff} is the LAI active in vapor and sensible heat exchange. For vegetation having a dense canopy, such as grass and alfalfa, LAI_{eff} = approximately 0.5 LAI. The 0.5 coefficient indicates that only the upper one half of a dense, one-dimensional canopy is effective in latent heat exchange. For open canopies of cattails and bulrushes, Allen et al. (1992) used LAI_{eff} = LAI.

Resistance Parameter Estimation

Application of the Penman-Monteith equation and supporting resistance equations requires the measurement or estimation of plant height and leaf area index. Leaf area indices of hydrophytes can often be estimated by multiplying average plant densities by the average width and heights of leaf blades and by the average number of blades per plant (Prueger, 1991; Allen et al. 1992). Allen et al. measured a maximum LAI/h ratio for dense cattails equal to 3.3 m^{-1} (3.3 LAI per m of height), with an average value of 2.6 m^{-1}. The average LAI/h ratio was 2.8 m^{-1} in bulrush stands.

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Prueger (1991) compared measured and estimated net radiation (Wright, 1982) over cattails and concluded that an albedo of 0.17 was the best estimate for cattails. Abtew and Obeysekera (1995) made the same conclusion.

In general, it is difficult to find a unique solution of roughness and surface resistance parameters during calibration of wetland measurements to a single layer Penman-Monteith equation. Allen et al., 1994 found a relatively "broad" plateau of roughness – surface resistance combinations that produced the same minimum estimation error. In some situations, z_{om}:H was best treated as a variable and estimated as a function of wind speed, and r_s was best estimated as 100 - 0.09 $(R_n - G)$, were R_n and G are in W m^{-2}. However, applying these algorithms did not statistically produce estimates that were more accurate than assuming that z_{om}:H = 0.12 and that r_s = 45 s m^{-1}.

Standard errors of estimate (SEE) calculated between P-M estimates and BR ET measurements in the Allen et al., (1994) study are reported in Table 1. Ratios between estimates and BR measurements were nearly 1.0 for all approaches since parameters in each approach were calibrated to the BR data. Values for SEE were similar among all methods, averaging about 0.08 mm for each 20-minute period of measurement, and were actually lowest for the K_c ET_o estimates. However all approaches produced similar results. SEE's averaged about 40% of the average ET during daylight periods.

Table 3. Ratios of Penman-Monteith estimates to Bowen Ratio measured ET and standard errors of estimate for twenty minute periods during August, 1993 for cattail vegetation at 9 ha Pelican Pond, Utah.

Method	Method for z_{om}: H	Method for z_{oh}: z_{om}	Method for r_s	Ratio of Est. to BR ET	Std. Error of Est, mm	Std. Error of Est., %
P-M	0.12	0.1	45 s m^{-1}	1.02	0.080	42
P-M	f(u)	0.1	100-0.09(R_n-G)	1.00	0.076	40
P-M	f(u)	f(u)	45 s m^{-1}	1.02	0.081	43
1.15ET_r	—	—	—	1.00	0.076	40
1.30 ET_o	—	—	—	1.01	0.073	38

(ET_r = alfalfa reference evapotranspiration; ET_o = grass reference evapotranspiration)

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Conclusions concerning best methods. The K_c ET_0 approach produces the most consistent estimates of wetland ET for a large area of cattail vegetation during the peak water use period. The P-M equation has the advantage over the K_c ET_0 method in that changes in vegetation density, height, leaf area and senescence can be visually quantified and incorporated into the P-M estimates. This advantage would be quite valuable when transferring measurements from one region to another and from one growing season to another. Variations in amounts and fractions of the wetland having standing water can be quantified in the P-M equation by computing a bulk r_s using parallel resistance theory.

SUMMARY

Generally, the agreement between estimated and measured ET is better using the simpler K_c ET_r approach than with the Penman-Monteith approach (Allen et al., 1992, 1994; Abtew and Obeysekera, 1995). This is due to some degree by the complexity of wetland canopies, and especially for small wetlands, where assumptions of large expanses of uniform vegetation in the Penman equation are violated. The K_c curves also incorporate all differences and changes in vegetation relative to the roughness crop, whereas, these differences must be explicitly characterized for the Penman-Monteith equation, which can be difficult.

Appendix 1--References

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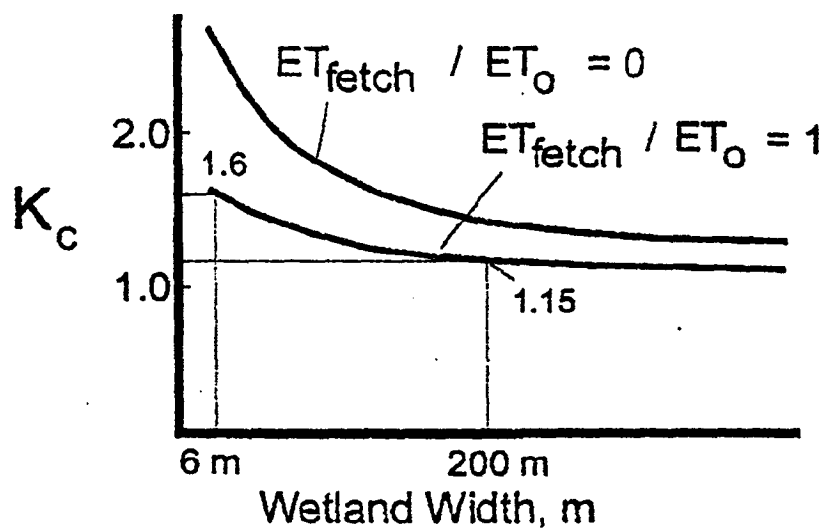
Fig. 1 Proposed K_c curve for peak ET periods for tall wetland vegetation (from Allen et al. 1994).
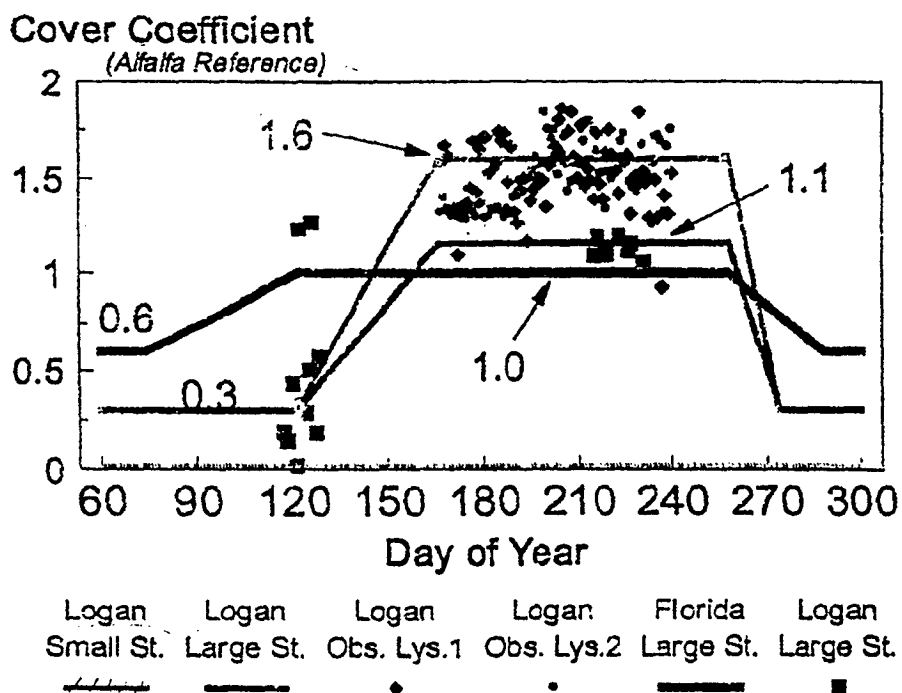

Fig. 2 K_c curves and observed data for cattail vegetation (small st. = small stand (area-wise); large st. = large stand (area-wise)).
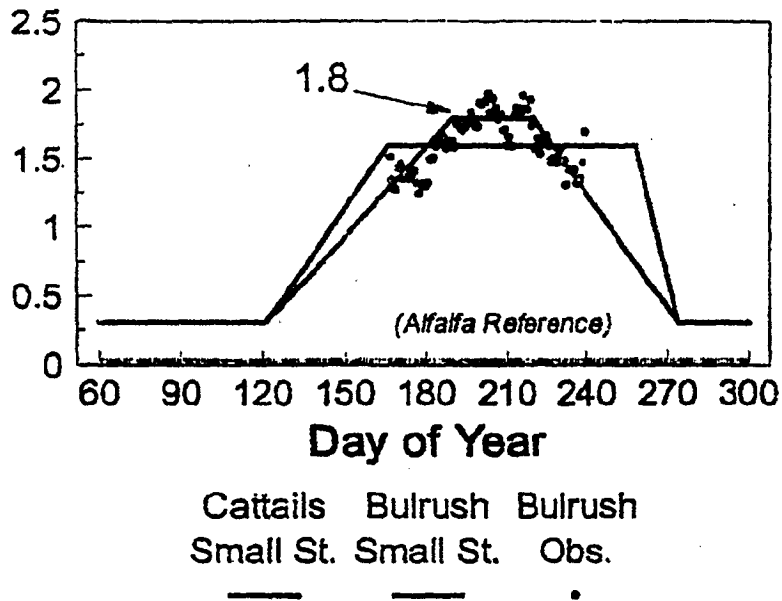
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Cover Coefficient

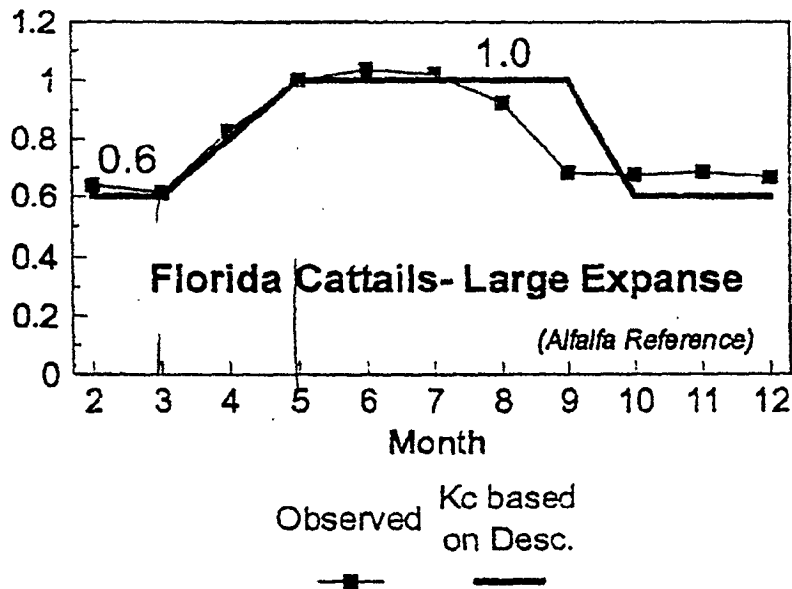Fig. 3 K_c curve and observed data for a narrow stand of bulrush vegetation near Logan, UT.

Fig. 4 Monthly K_c determined from data reported by Abtew and Obeysekera (1995) for a large cattail wetland in southern Florida. The length of the curve was based on descriptions given by the paper.

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Cattail Wetlands, Logan
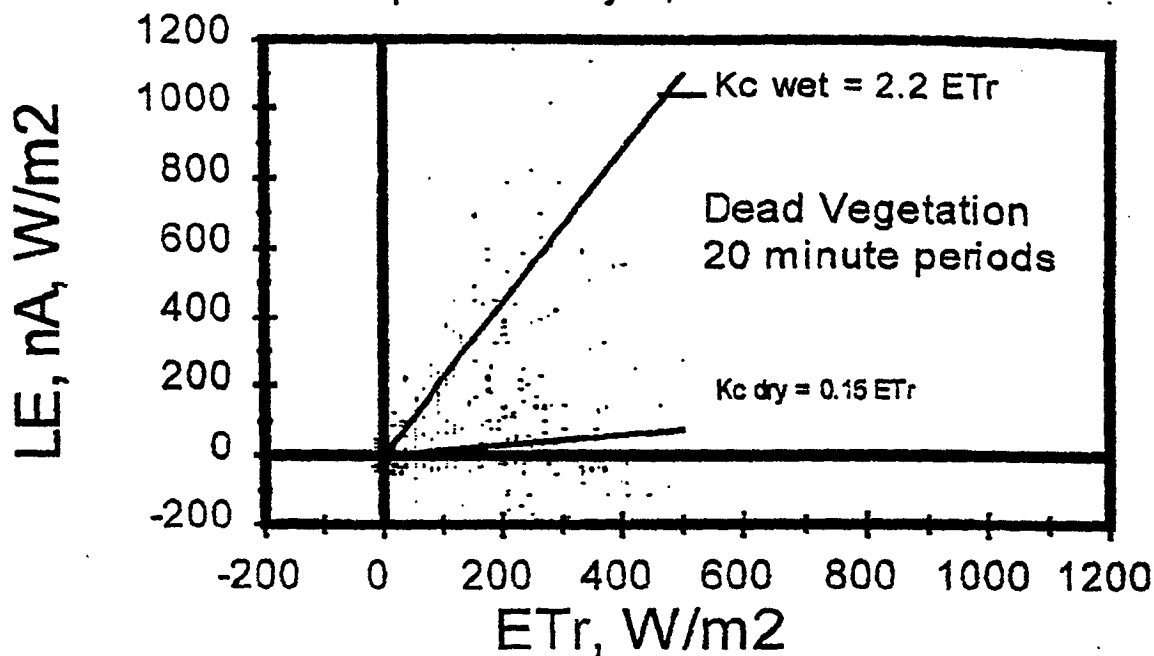April 26 - May 9, 1995

Fig. 5   20-minute recordings of evaporation from a dormant cattail wetland (LE) vs. alfalfa reference ET_r for periods during and following rainfall events and for periods having dry (and dead) vegetation during late April - early May in Logan, UT.
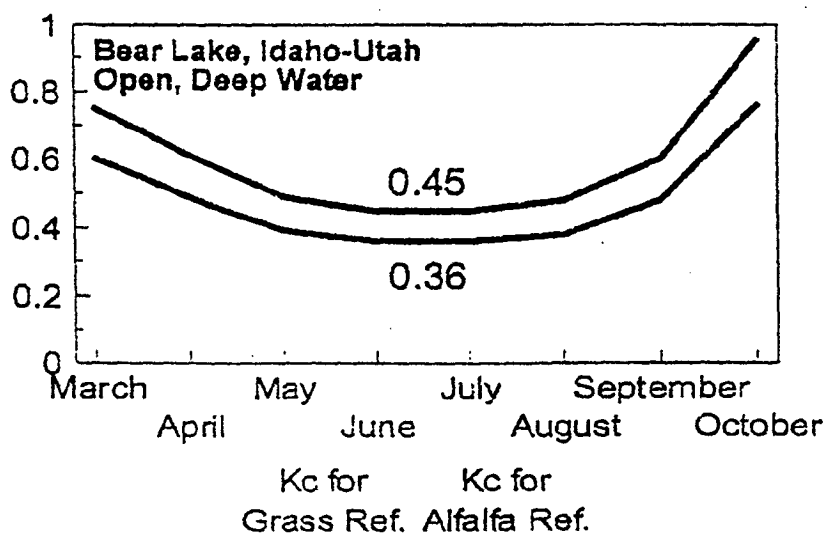

Evaporation Coefficient

Fig. 6   "K_c" coefficients for evaporation from a large, deep lake in Utah-Idaho as measured using Bowen ratio and eddy correlation systems (from Amayreh, 1995).

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